

Future Perspectives on STAR Exotic Searches



Outline

- **Advantages of RHIC/STAR.**
- **STAR's exotic search programs.**
- **Summary.**

RHIC is Flexible

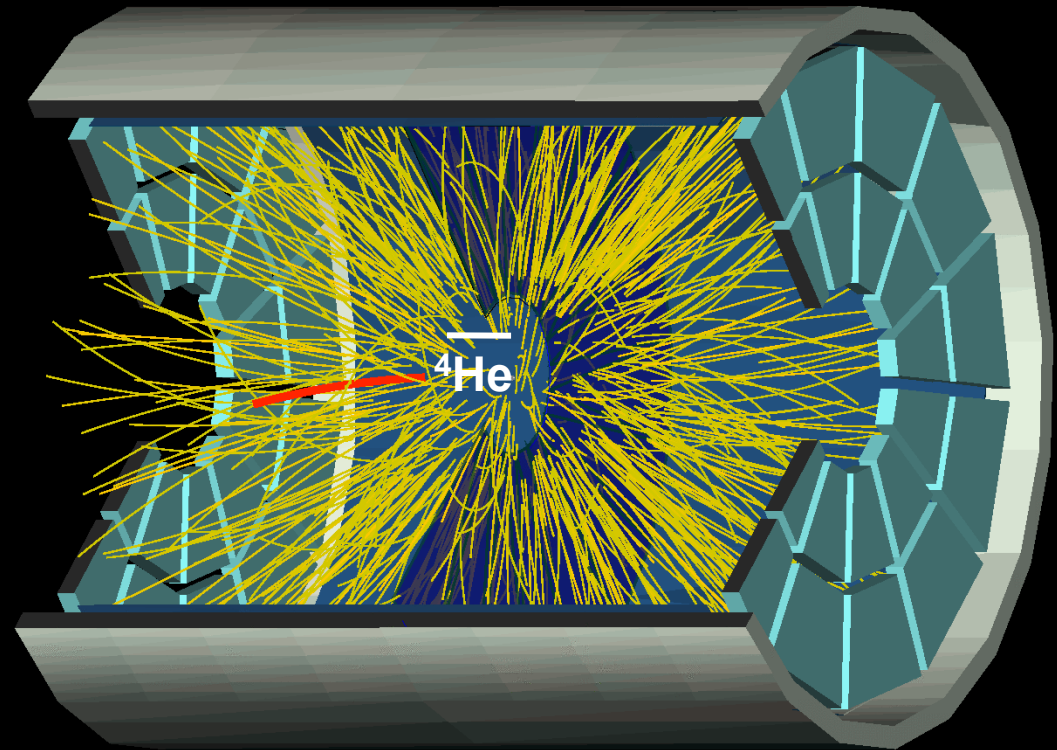
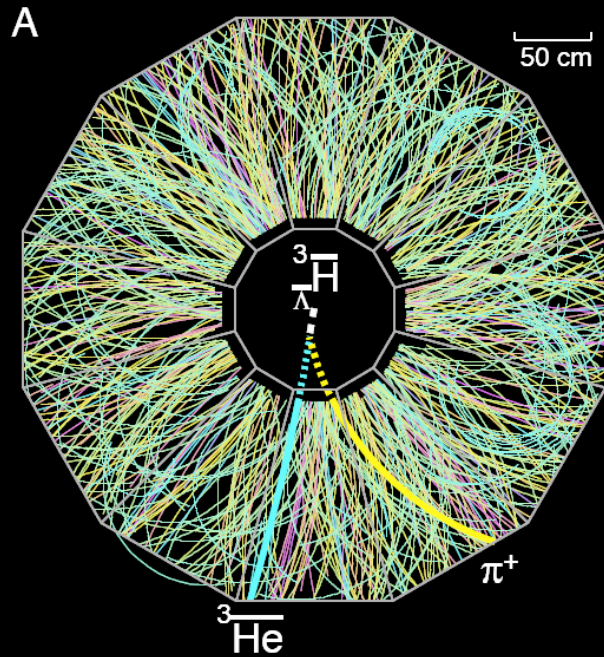
| C.M. Energy per nucleon pair (GeV) | Collision Species |
|------------------------------------|-----------------------------------|
| 500 | Polarized p+p |
| 200 | Polarized p+p, Au+Au, d+Au, Cu+Cu |
| 130 | Au+Au |
| 62.4 | Polarized p+p, Au+Au, Cu+Cu |
| 39 | Au+Au |
| 19.6—22.4 | Au+Au, Cu+Cu |
| 11 | Au+Au |
| 7.7 | Au+Au |
| 9.2 | Au+Au test |
| 200 | U+U and/or Cu+Au (2012) |

RHIC is Bright

- **Annual Au+Au collisions to tape : STAR : ~1 billion; PHENIX: ~10 billion.**
- **Luminosity p+p equivalent: possibly up to fb^{-1} .**
- **Annual particles to tape: $> 10^{12}$.**

RHIC is Exotic/Antimatter-rich

100 cm



Science

Science 328, 58 (2010)

nature

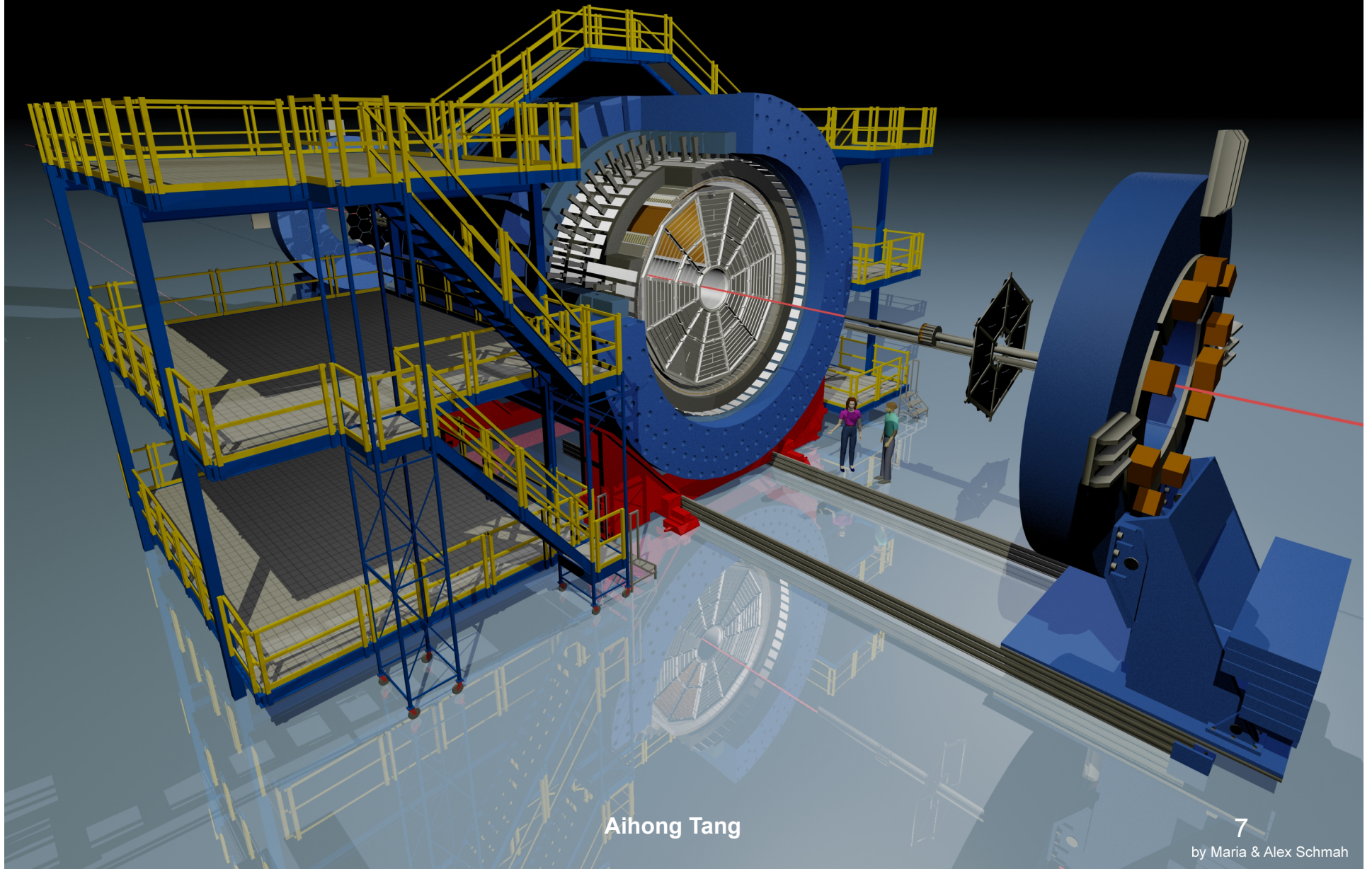
Nature 473, 353 (2011)



AntiHelium
discovery made into
top 100 stories of
2011 :

#20 in all disciplines,
#3 in Physics.

STAR : Uniform and Large Acceptance

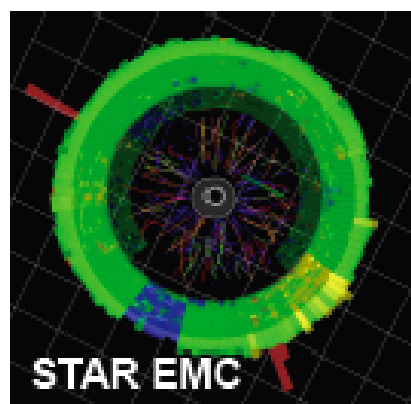
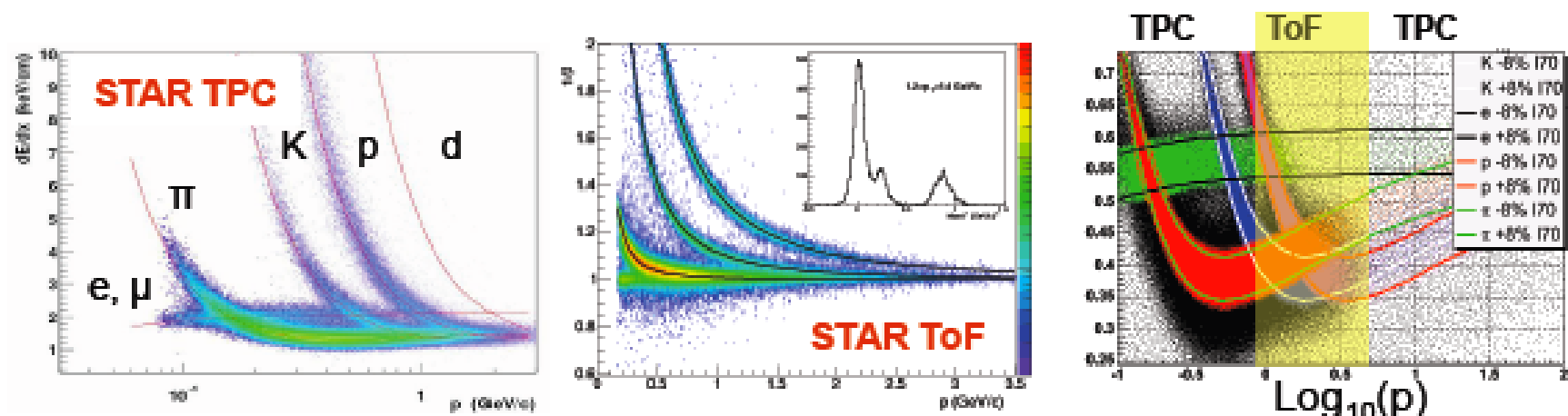


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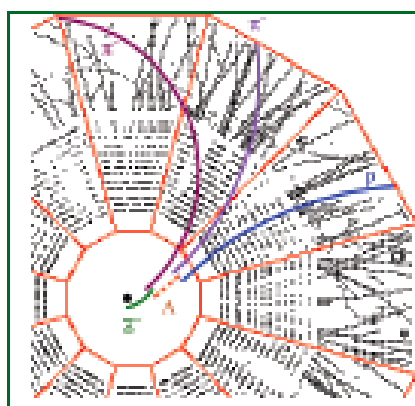
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by Maria & Alex Schmah

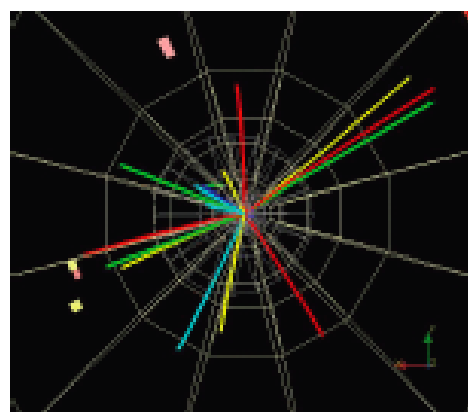
STAR : Excellent PID and Tracking



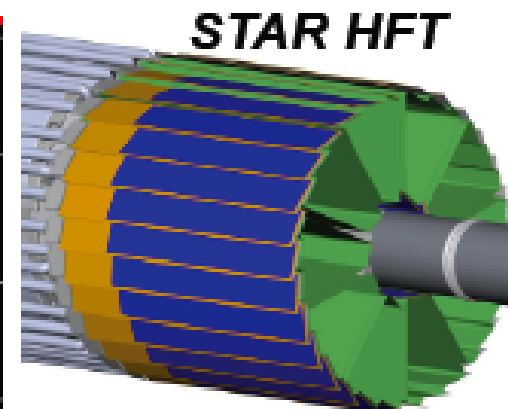
Neutral particles



Strange hyperons



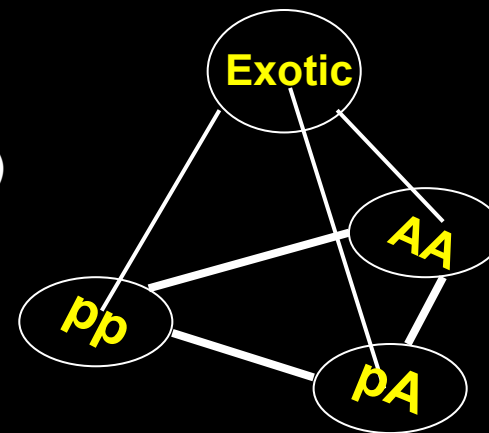
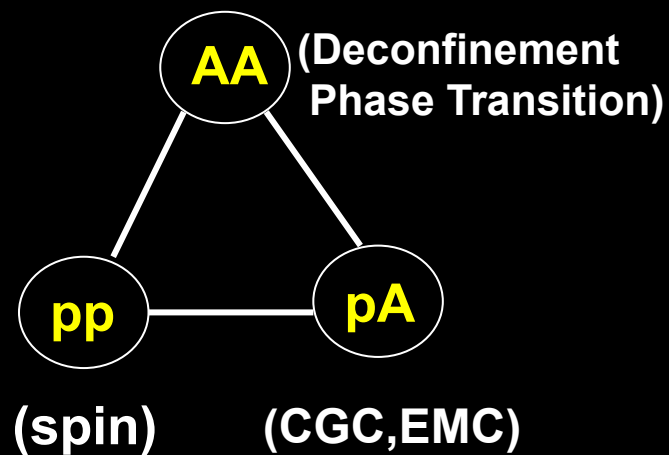
Jets



Heavy Quark Hadrons

Exotic/Rare Phenomena at RHIC

RHIC : QCD Machine & Beyond



Courtesy of H. Huang

A New Dimension to RHIC Physics

Exotic/Rare Particle Search in STAR

Push the boundary of Standard Model

- Dibaryon at midrapidity
- Strangelet search at forward region

Look for new physics beyond Standard Model

- Rare decays
- Antimatter

Atom/parton chemistry test ground

- Atomcules
- Muonic Atoms
- Glueball

Extension and beyond RHIC-II

- Potentials at EIC

The H^0 -Dibaryon

Strangelet

6 quark-bag bound state (uuddss)

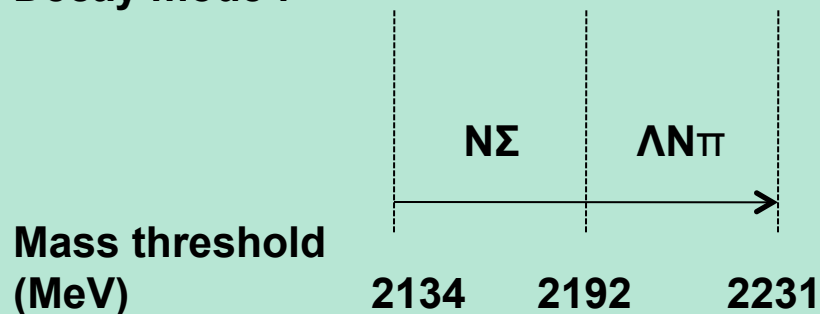
$$m_{H^0} < 2m_{\Lambda} = 2231 \text{ MeV}$$

Stable against strong decay but not against weak hadronic decay

$$\tau = 10^{-8} - 10^{-10} \text{ s}$$

(R. Jaffe PRL 38 195 (1977), Donoghue'86 ...)

Decay mode :



Hadronic Counterpart

$$(\Lambda\Lambda)_b$$

Other dibaryons might exist as bound states made by coalescence of 2 strange baryons

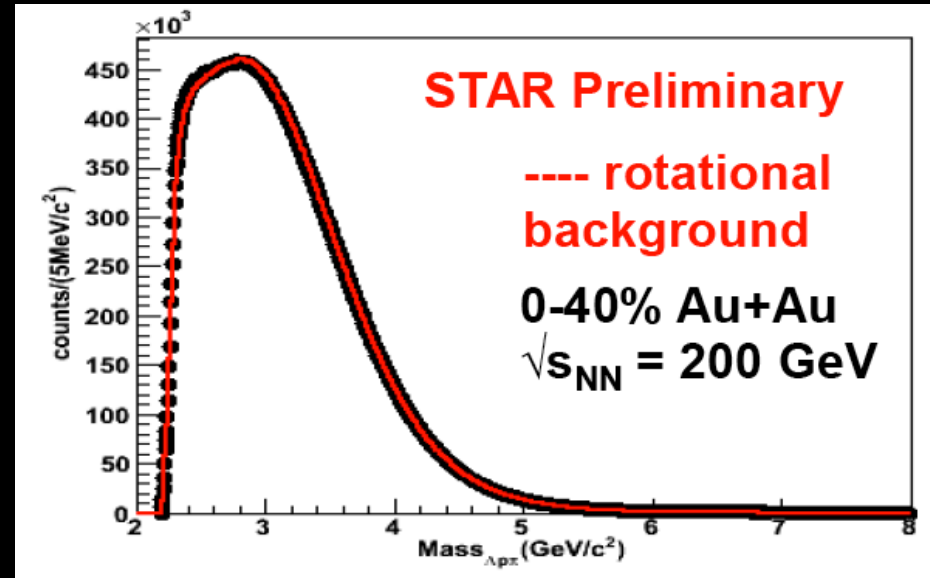
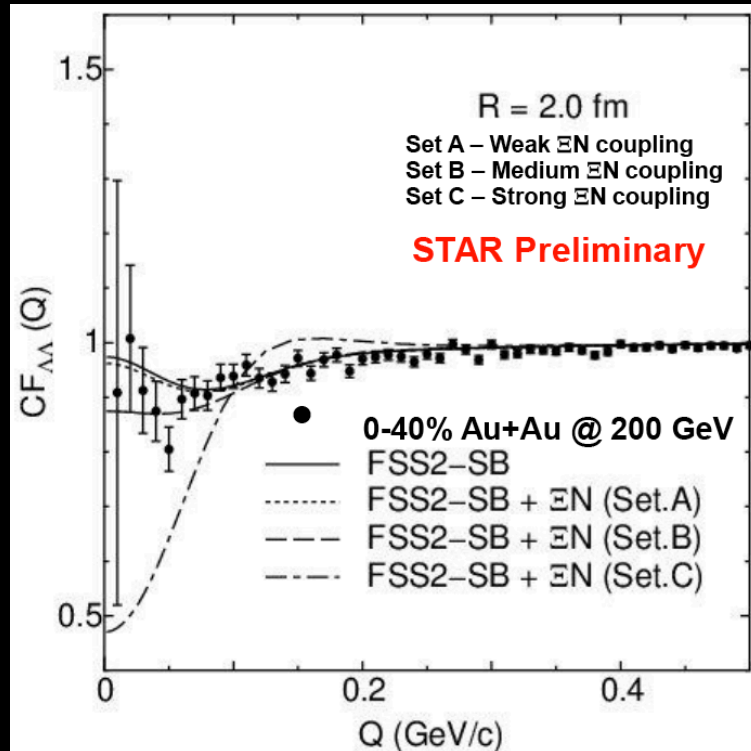
(Schaffner-Bielich et al PRL 84 (2000) ...)

Decay length $\sim 1-5\text{cm}$

$$\begin{aligned}
 (\Lambda\Lambda)_b &\rightarrow \Lambda + p + \pi \\
 &\rightarrow \Sigma^- + p
 \end{aligned}
 \left. \vphantom{\begin{aligned} (\Lambda\Lambda)_b &\rightarrow \Lambda + p + \pi \\ &\rightarrow \Sigma^- + p \end{aligned}} \right\} dN/dy \sim 10^{-2} - 10^{-3} / \text{event}$$

$$\begin{aligned}
 (\Sigma^+ p)_b &\rightarrow p + p \\
 (\Xi^0 p)_b &\rightarrow \Lambda + p \\
 (\Xi^0 \Lambda)_b &\rightarrow \Lambda + \Lambda \\
 &\rightarrow \Xi^- + p
 \end{aligned}
 \left. \vphantom{\begin{aligned} (\Sigma^+ p)_b &\rightarrow p + p \\ (\Xi^0 p)_b &\rightarrow \Lambda + p \\ (\Xi^0 \Lambda)_b &\rightarrow \Lambda + \Lambda \\ &\rightarrow \Xi^- + p \end{aligned}} \right\} dN/dy \sim 10^{-3} / \text{event}$$

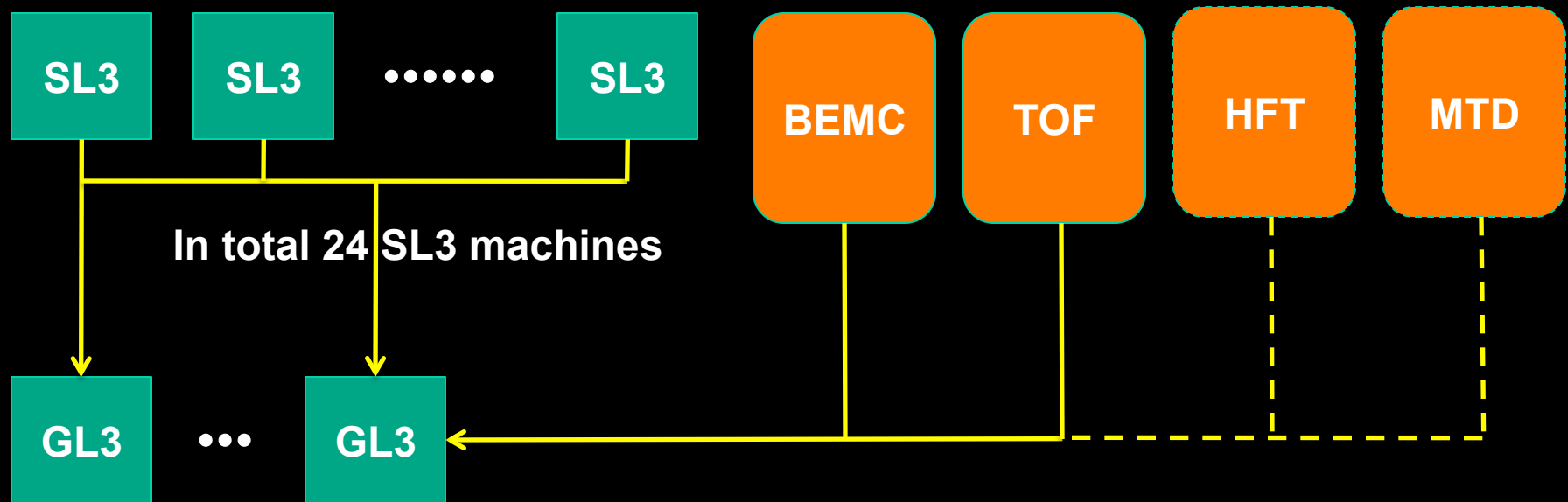
The H^0 -Dibaryon



N. Shah (for the STAR Collaboration),
 this workshop

Active ongoing effort

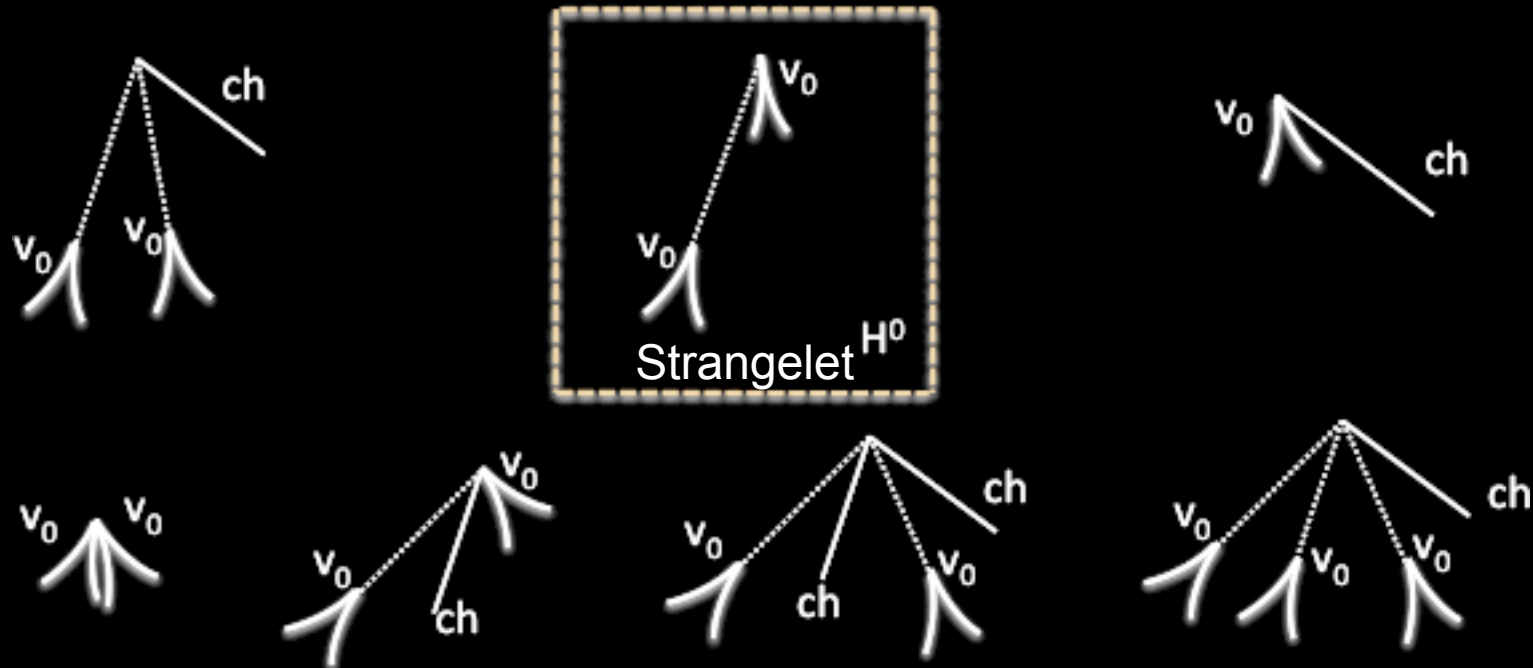
The H^0 -Dibaryon : HLT as trigger



- Sector tracking (SL3) in DAQ machines (24 in total, each for a TPC sector).
- Information from subsystems (SL3 and others) are sent to Global L3 machines (GL3) where an event is assembled and a trigger decision is made.

Online Event tagger/trigger
Fast physics output with HLT

The H^0 -Dibaryon : How to trigger



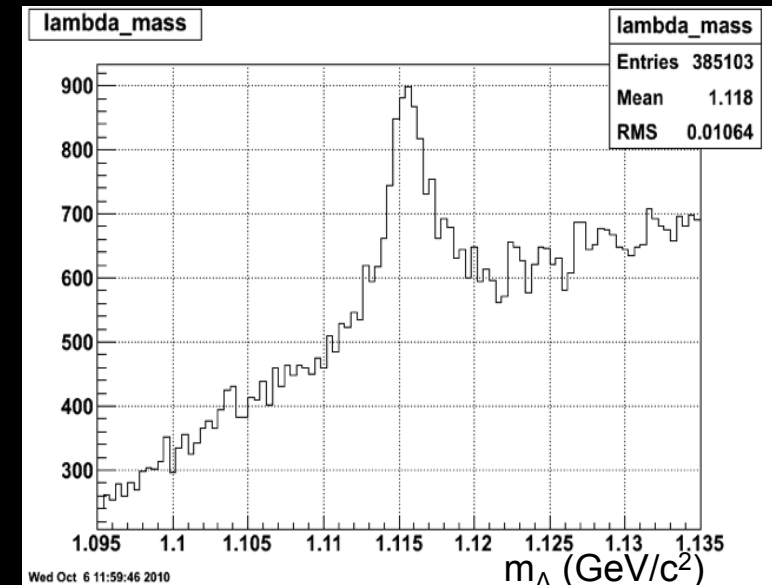
Trigger on secondary decay topologies (with GPU acceleration) → potential for new discoveries

The H^0 -Dibaryon Reconstruction : GPU acceleration

Test result :
GPU (Nvidia GTX280) vs CPU (Intel 2.8 G)

| | CPU | GPU (GeForce GTX 280) |
|-----------|-----------|------------------------------|
| clock | 2.80GHz | 1.3GHz |
| Time cost | 93us/pair | 1.3us/pair |

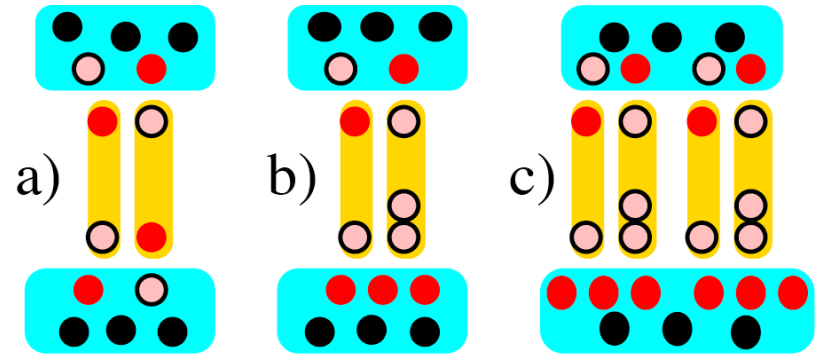
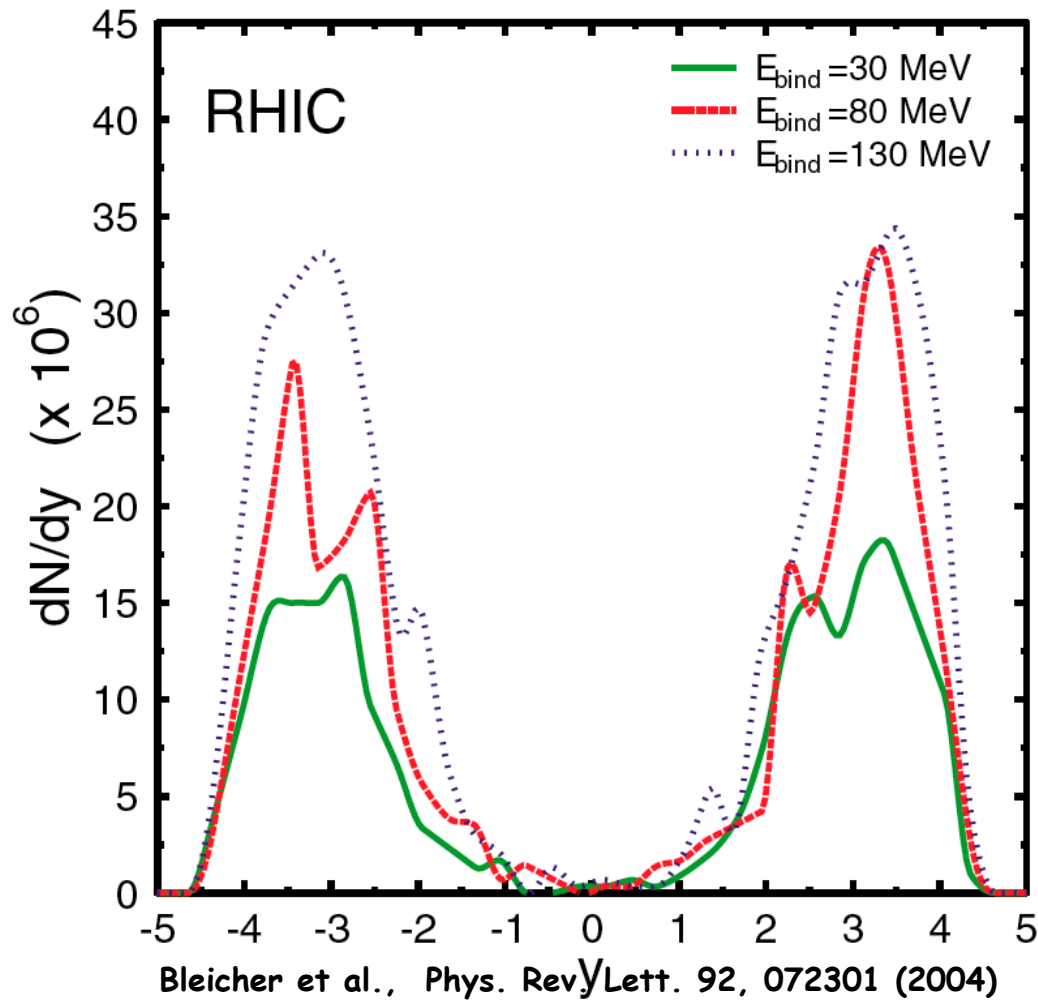
GPU is **60** times faster than single CPU
Core considering data transmission.



Lambda reconstructed by GPU
(real data from run10 AuAu 200GeV,
HLT tracks).

**GPU significantly accelerates v_0 reconstruction
R&D ongoing. Seeking funding.**

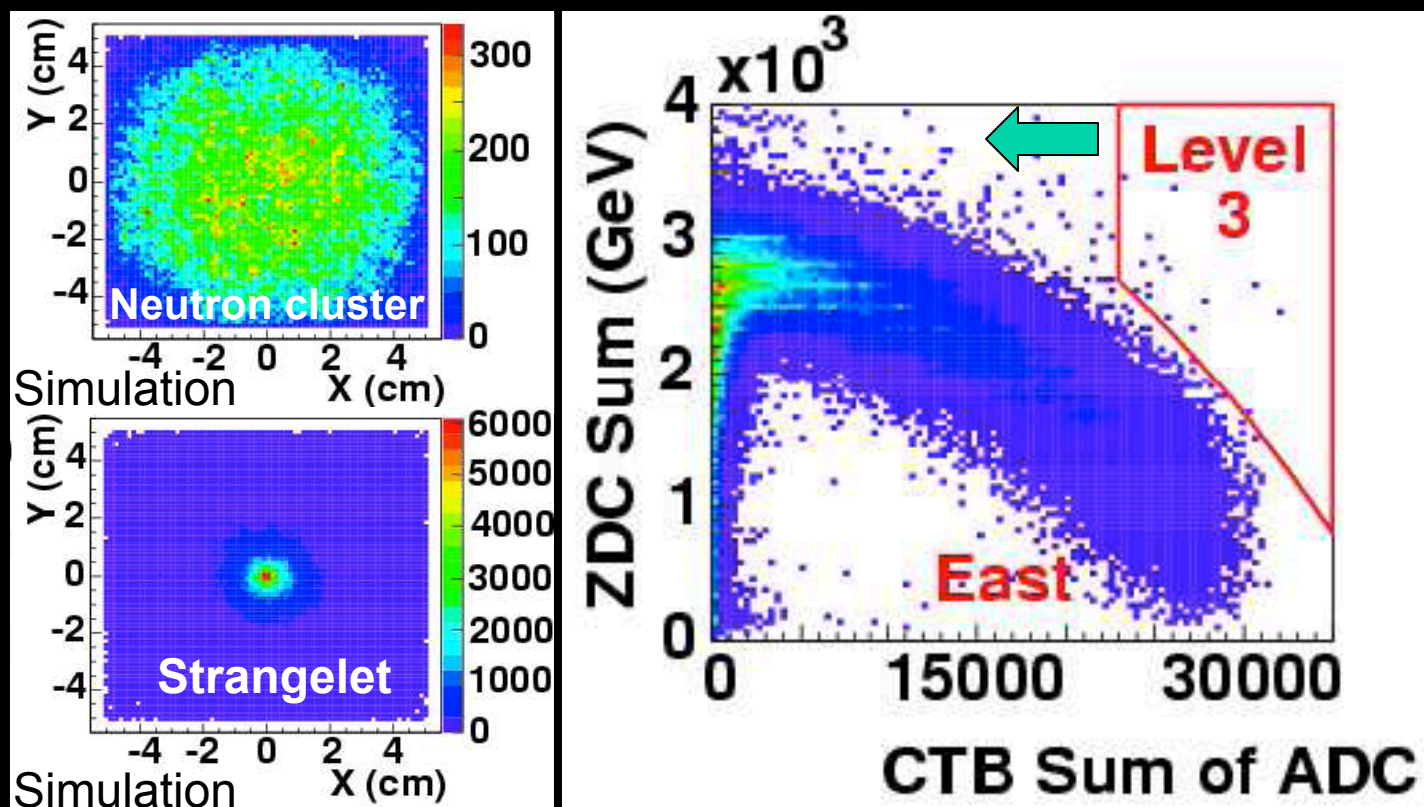
Strangelet Search in Forward Region



**Strangelet formed in remnants
by compensating the flavor
change due to pomeron
breaking.**

Peaked in beam directions

Strangelet Search in Forward Region



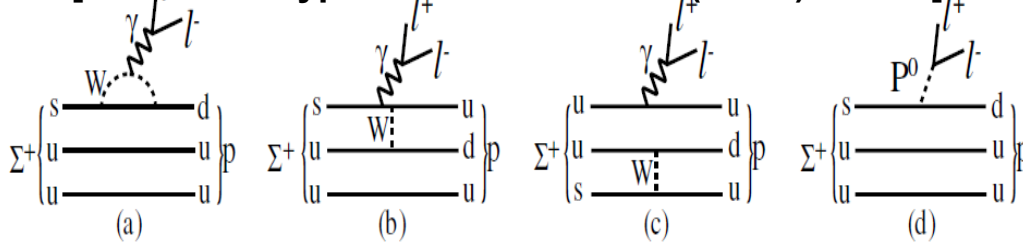
STAR, PRC 76, 011901 (2007)

Revisit the strangelet search in forward region by moving away from central collisions.

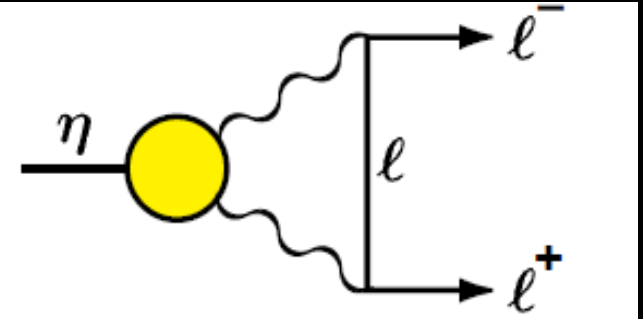
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Rare Decays

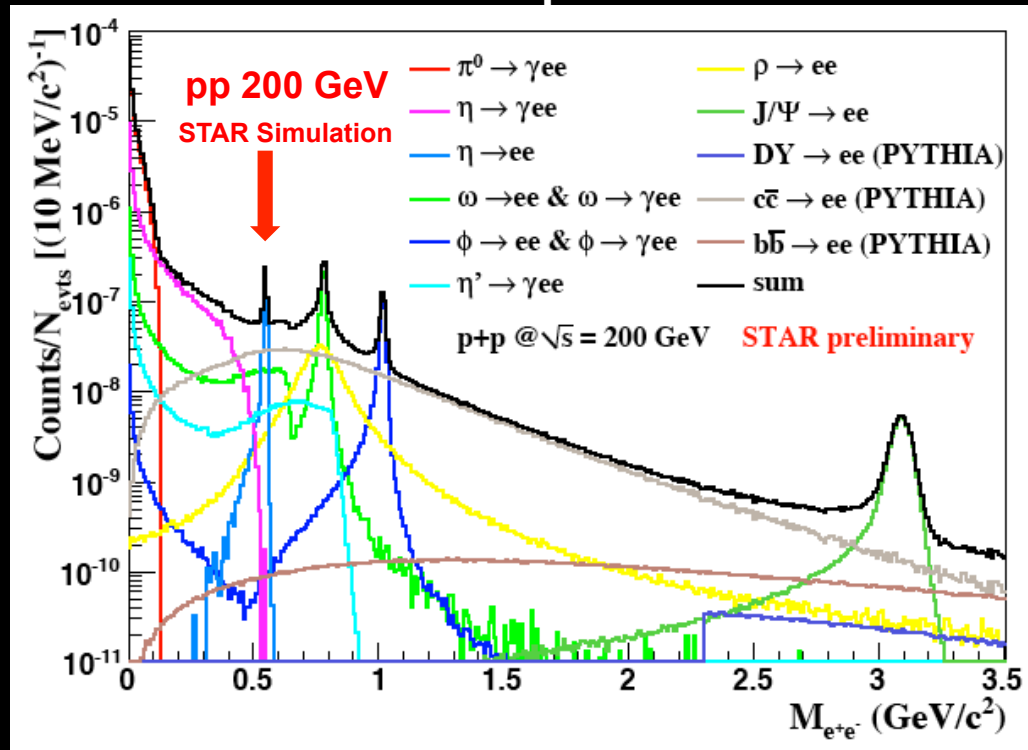
[Park et al. HyperCP Collab. PRL94(2005)021801]



$\Sigma \rightarrow p \ell^+ \ell^-$



$\eta \rightarrow \ell^+ \ell^-$

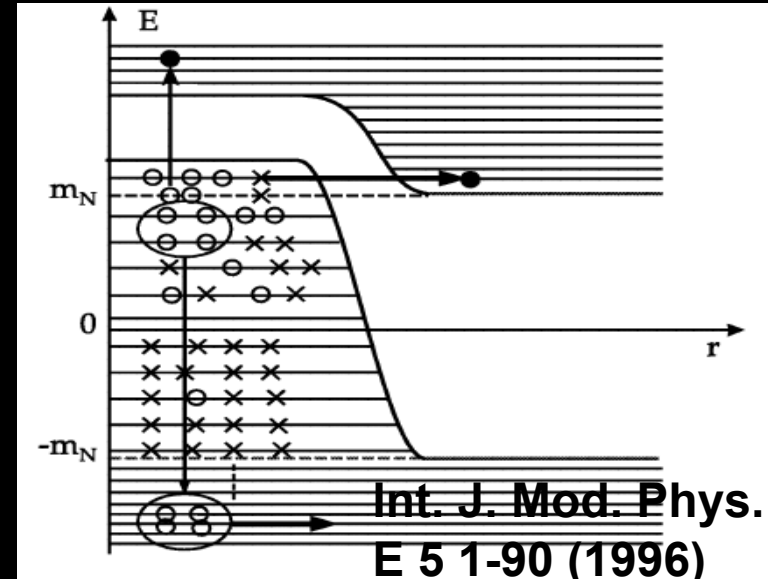
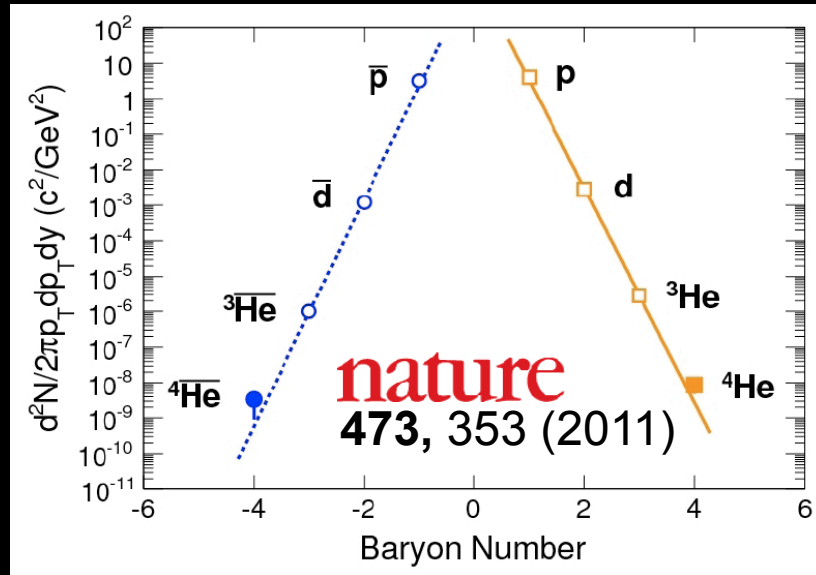


Search for traces of New Physics beyond the standard model.

These decays usually involve EM or weak coupling which can be calculated to high accuracy.

STAR has high rate capability and excellent lepton ID at low momentum.

Antimatter



Idea from Walter Greiner: correlations are present in vacuum, allowing antinucleus like anti- α to be directly excited from the vacuum. Rate could be much larger than low value predicted by statistical coalescence.

No evidence but we should watch for it.

Antimatter

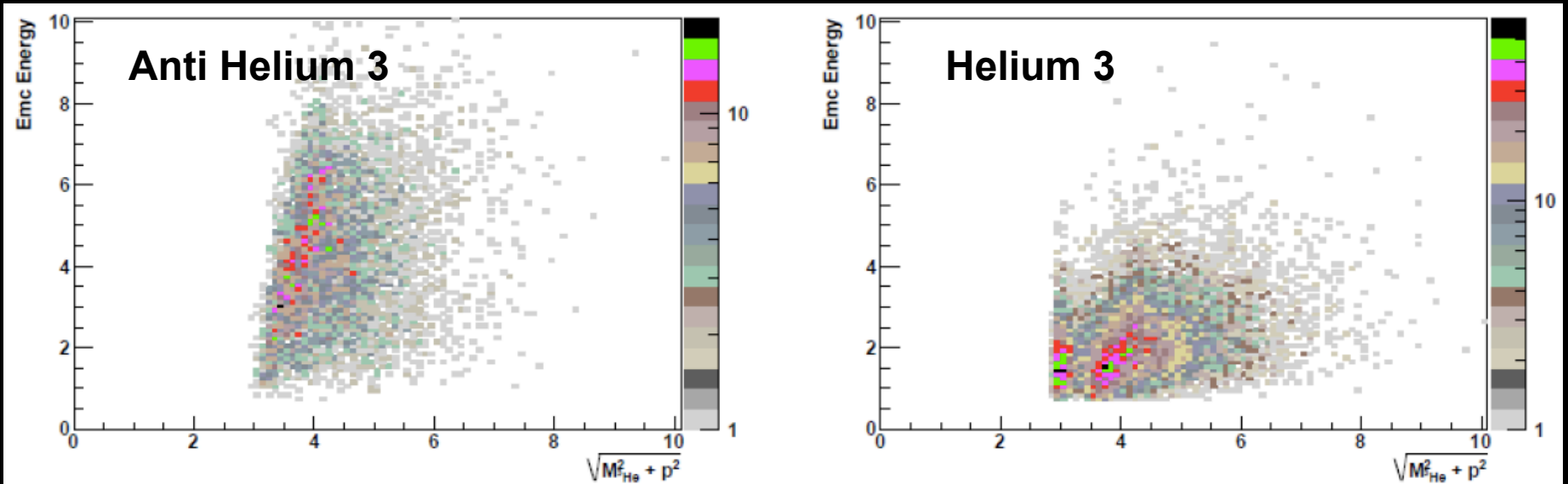
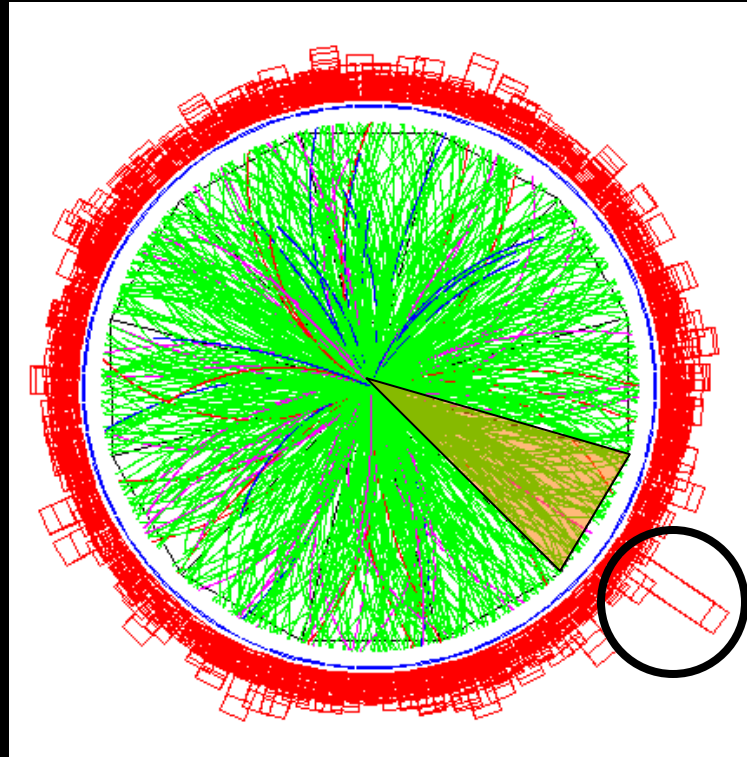


Figure 2.52: Left panel: ${}^3\overline{He}$ EMC energy vs TPC $\sqrt{m^2 + p^2}$. Right panel: same for 3He .

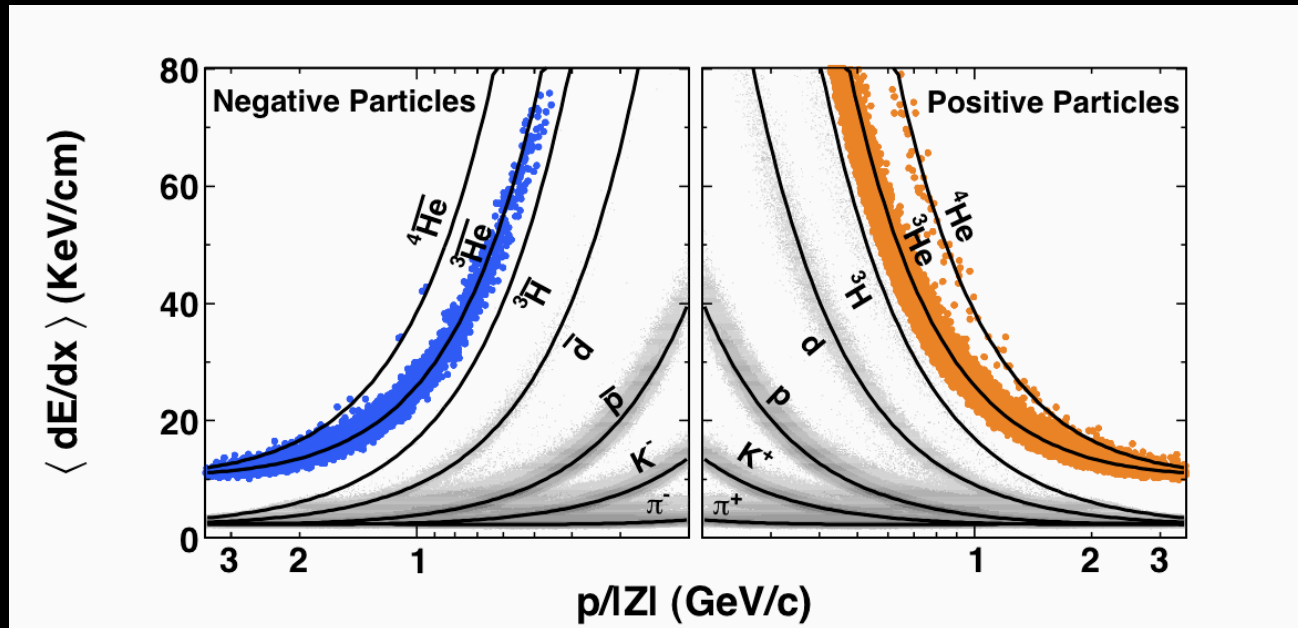
Trigger on antimatter with BEMC
Look for possible heavier antimatter and enrich
samples for (anti)hypernuclei studies.

Antimatter



**DAQ 10K, readout a TPC sector of interest only
Significantly increase DAQ speed.**

Benefit from Anti(nuclei)-rich environment



A = 4, or 5 unstable (anti)nuclei :

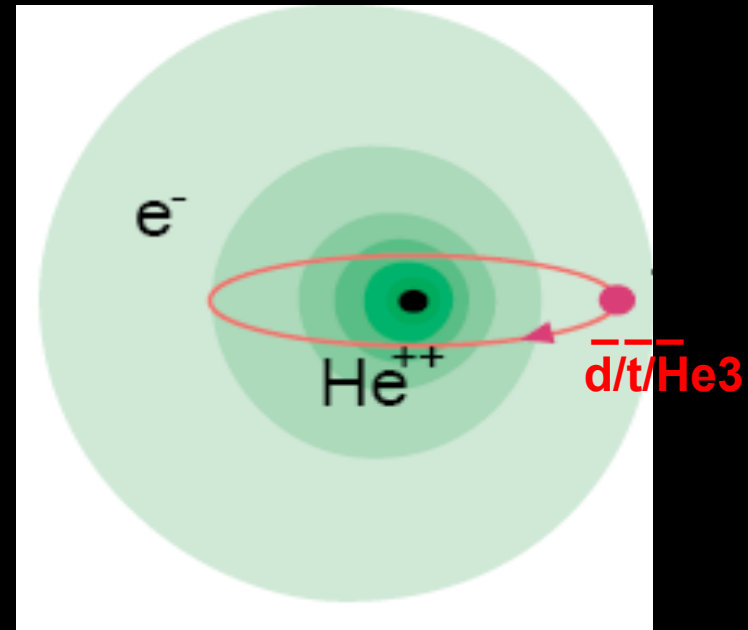
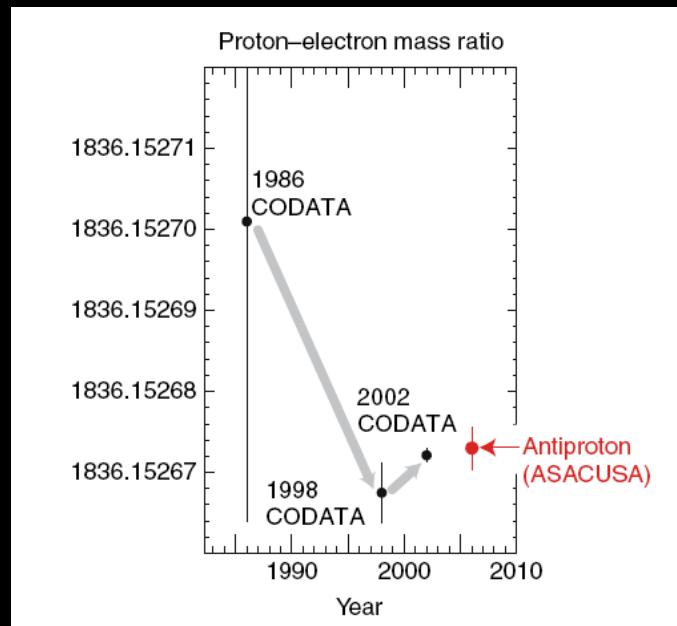
S = 2 or 3 (anti)hypertriton :



.....

Rich light (anti)nuclei environment offers new opportunities

Creating First Antinucleus Atomcules



Metastable antiproton-helium atom discovered at KEK: Iwasaki, PRL 67 (1991); nature 361 (1993) 238

Mass difference: $p\text{-}p\bar{p} < 2 \times 10^{-9}$; Hori, PRL 96 (2006);

measurement of baryon mass and magnetic moment for CPT test at LEAR/CERN

<http://asacusa.web.cern.ch/ASACUSA/index-e.html>

What if we replace antiproton with antiDeuteron, antiTriton or antiHelium3 ?

Only RHIC can address this question with enough antimatter nuclei.

Measure Antinucleus mass (CPT test)

Antinucleus-nucleus annihilation

Muon Atoms

PHYSICAL REVIEW D
VOLUME 48, NUMBER 9

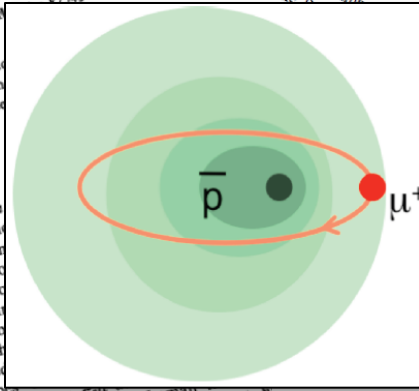
Production of muon-meson atoms in ultrarelativistic heavy-ion collisions

Gordon Baym,* Gerald Friedman, R. J. Hughes, and Barbara V. Jacak
Los Alamos National Laboratory, Los Alamos, New Mexico 87545
(Received 9 November 1992)

Ultrarelativistic heavy-ion collisions should produce hydrogen-like muon-meson atoms. Such atoms could provide a convenient way to measure the production rate of pion-muon atoms expected in these collisions. We estimate the production rate of pion-muon atoms expected in these collisions. We estimate the production rate of pion-muon atoms expected in these collisions.

PACS number(s): 25.75.+r, 13.85.Rm, 24.60.Ky, 36.10.-k

Soft leptons produced in the early evolution of an ultrarelativistic heavy-ion collision are a potentially important probe of the collision volume. It is difficult to measure the spectrum of directly produced soft leptons because of the large number of charged particles created in the collision and the need to separate the directly produced leptons from those arising from hadronic decays. However, it has been suggested [1] that the detection of muon-meson atoms, consisting of a muon and a meson, is a method to study the soft lepton spectrum. With magnetic analysis, such neutral atoms can be readily separated from the large flux of charged particles [2]. On the other hand, π - π and K - K atoms annihilate long before detection, and muons produced by most weak hadronic decays are not captured by directly produced mesons to form atoms because they are generally made too late in the evolution of the collision. Pion-muon atoms provide a sample of muons of transverse momentum below 1 GeV/c, a momentum range otherwise experimentally inaccessible due to contamination by muons from hadronic decays and difficulties in particle identification. Measurements in this range are capable of probing thermal electromagnetic emission processes in an initial plasma with a temperature ~ 200 MeV.



PHYSICAL REVIEW C
VOLUME 59, NUMBER 5

Hydrogenlike atoms from ultrarelativistic nuclear collisions

Joseph Kapusta* and Agnes Mocsy†
School of Physics and Astronomy, University of Minnesota, Minneapolis, Minnesota 55455
(Received 3 December 1998)

Hydrogenlike atoms produced when heavy nuclei collide is estimated for central collisions using the sudden approximation of Baym et al. A measurement of the hydrogen and hadron spectra with a spectrometer at low momentum where a direct experiment is not possible.

NUMBER 16

PHYSICAL REVIEW LETTERS

19 APRIL 1982

Measurement of the Rate of Formation of Pi-Mu Atoms in K_L^0 Decay

Aronson, R. H. Bernstein, G. J. Bock, R. D. Cousins, Jr.,^(a) J. F. Greenhalgh,^(b) D. Hedin,^(c) M. Schwartz, T. K. Shea, G. B. Thomson,^(d) B. Winstein
^(a) National Laboratory, Upton, New York 11973, and ^(b) University of Chicago, Chicago, Illinois 60637, and ^(c) Stanford University, Stanford, California 94305, and ^(d) University of Wisconsin, Madison, Wisconsin 53706
(Received 5 February 1982)

Hydrogenlike atoms consisting of a pion and a muon can be formed in $K_L^0 \rightarrow \pi\mu\nu$ decays. In an intense, high-energy K_L^0 beam, 320 pi-mu atoms were detected and simultaneously the K_L^0 flux was monitored by recording ordinary $K_L^0 \rightarrow \pi\mu\nu$ decays. The first measurement is reported of the branching ratio $R = \Gamma(K_L^0 \rightarrow \pi\mu\text{-mu atom} + \nu)/\Gamma(K_L^0 \rightarrow \pi\mu\nu) = (3.88 \pm 0.41) \times 10^{-7}$, using a subset of 155 atoms. This ratio may be sensitive to anomalous interactions between the pion and the muon. In the absence of such interactions, theory predicts $R = (4.43 \pm 0.12) \times 10^{-7}$.

PACS numbers: 13.20.Eb, 13.60.-r, 14.40.Aq, 36.10.-k

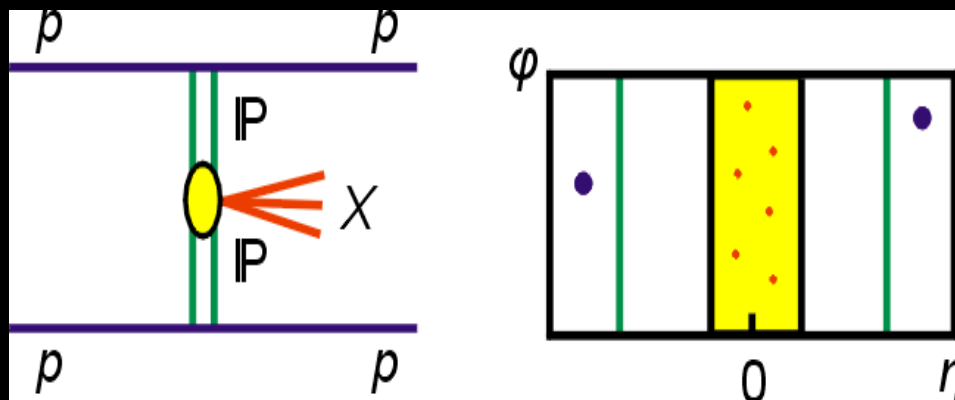
Exciting new possibilities: Muon Hydrogen-like atoms, Muon-meson Atoms.
Direct measure of single lepton spectrum from thermal radiation.
Large TOF signal with dissociation at beam structure.

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24

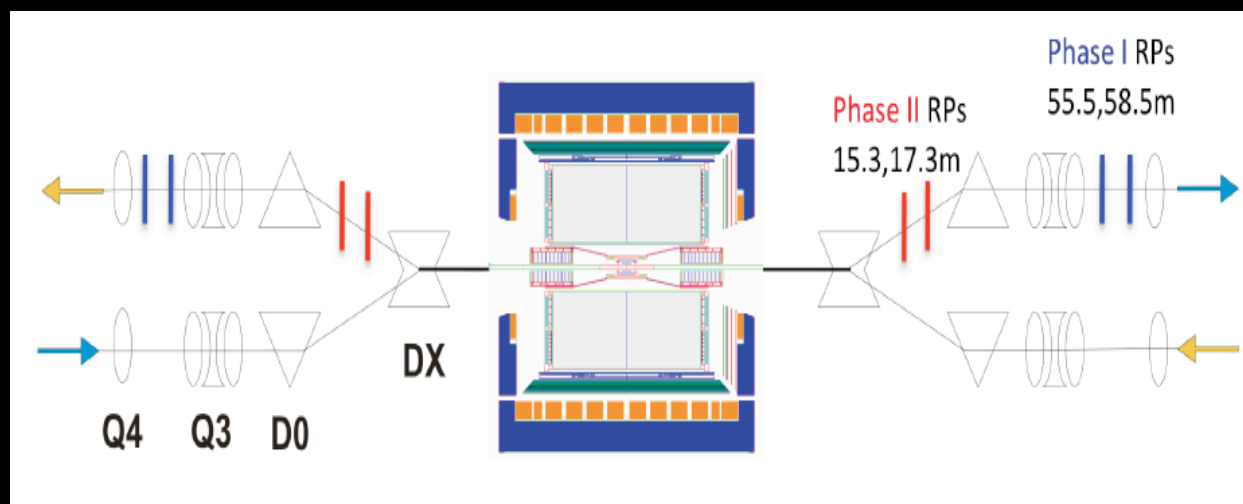
Glueball Search with Roman Pots

Phase II pp2pp at STAR



$$pp \rightarrow pM_Xp$$

Because of the constraints provided by the double Pomeron interaction, glueballs, hybrids, and other states coupling preferentially to gluons, will be produced with much reduced backgrounds compared to standard hadronic production processes. The massive system could form resonances, heavy flavour ...



A rich physics program with tagged forward protons in polarized p+p scattering at RHIC

Discovery Potential at EIC

<http://belle.kek.jp/belle/talks/moriondQCD10/pakhlov.ppt>
Many (>10) states poorly consistent with quark model

| State | M (MeV) | Γ (MeV) | J^{PC} | Decay Modes | Production Modes |
|--------------|---------------------|--------------------|------------|--|---|
| $Y_s(2175)$ | 2175 ± 8 | 58 ± 26 | 1^{--} | $\phi f_0(980)$ | e^+e^- (ISR) $J/\psi \rightarrow \eta Y_s(2175)$ |
| $X(3872)$ | 3871.4 ± 0.6 | < 2.3 | 1^{++} | $\pi^+\pi^- J/\psi$, $\gamma J/\psi, D\bar{D}^*$ | $B \rightarrow KX(3872), p\bar{p}$ |
| $X(3915)$ | 3914 ± 4 | 23 ± 9 | $0/2^{++}$ | $\omega J/\psi$ | $\gamma\gamma \rightarrow X(3915)$ |
| $Z(3930)$ | 3929 ± 5 | 29 ± 10 | 2^{++} | $D\bar{D}$ | $\gamma\gamma \rightarrow Z(3940)$ |
| $X(3940)$ | 3942 ± 9 | 37 ± 17 | $0^{?+}$ | $D\bar{D}^*$ (not $D\bar{D}$ or $\omega J/\psi$) | $e^+e^- \rightarrow J/\psi X(3940)$ |
| $Y(3940)$ | 3943 ± 17 | 87 ± 34 | $?^{?+}$ | $\omega J/\psi$ (not $D\bar{D}^*$) | $B \rightarrow KY(3940)$ |
| $Y(4008)$ | 4008^{+82}_{-49} | 226^{+97}_{-80} | 1^{--} | $\pi^+\pi^- J/\psi$ | e^+e^- (ISR) |
| $X(4160)$ | 4156 ± 29 | 139^{+113}_{-65} | $0^{?+}$ | $D^* \bar{D}^*$ (not $D\bar{D}$) | $e^+e^- \rightarrow J/\psi X(4160)$ |
| $Y(4260)$ | 4264 ± 12 | 83 ± 22 | 1^{--} | $\pi^+\pi^- J/\psi$ | e^+e^- (ISR) |
| $Y(4350)$ | 4361 ± 13 | 74 ± 18 | 1^{--} | $\pi^+\pi^- \psi'$ | e^+e^- (ISR) |
| $X(4630)$ | 4634^{+9}_{-11} | 92^{+41}_{-32} | 1^{--} | $\Lambda_c^+ \Lambda_c^-$ | e^+e^- (ISR) |
| $Y(4660)$ | 4664 ± 12 | 48 ± 15 | 1^{--} | $\pi^+\pi^- \psi'$ | e^+e^- (ISR) |
| $Z(4050)$ | 4051^{+24}_{-23} | 82^{+51}_{-29} | $?$ | $\pi^\pm \chi_{c1}$ | $B \rightarrow KZ^\pm(4050)$ |
| $Z(4250)$ | 4248^{+185}_{-45} | 177^{+320}_{-72} | $?$ | $\pi^\pm \chi_{c1}$ | $B \rightarrow KZ^\pm(4250)$ |
| $Z(4430)$ | 4433 ± 5 | 45^{+35}_{-18} | $?$ | $\pi^\pm \psi'$ | $B \rightarrow KZ^\pm(4430)$ |
| $Y_b(10890)$ | $10,890 \pm 3$ | 55 ± 9 | 1^{--} | $\pi^+\pi^-\Upsilon(1, 2, 3S)$ | $e^+e^- \rightarrow Y_b$ |

observed last 6 years by B-factories

Heavy Flavor States Discovered by B-factories

**With high baryon density, RHIC has the potential for
discovering heavy flavor & baryon hybrid states**

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Heavy flavor hypernuclei

Predicted to exist (PRL 39, 1506 (1977))

Not produced in pp, ep collisions

**Not produced in fixed target
experiment.**

**EIC has enough energy for charm
and bottom hypernuclei.**

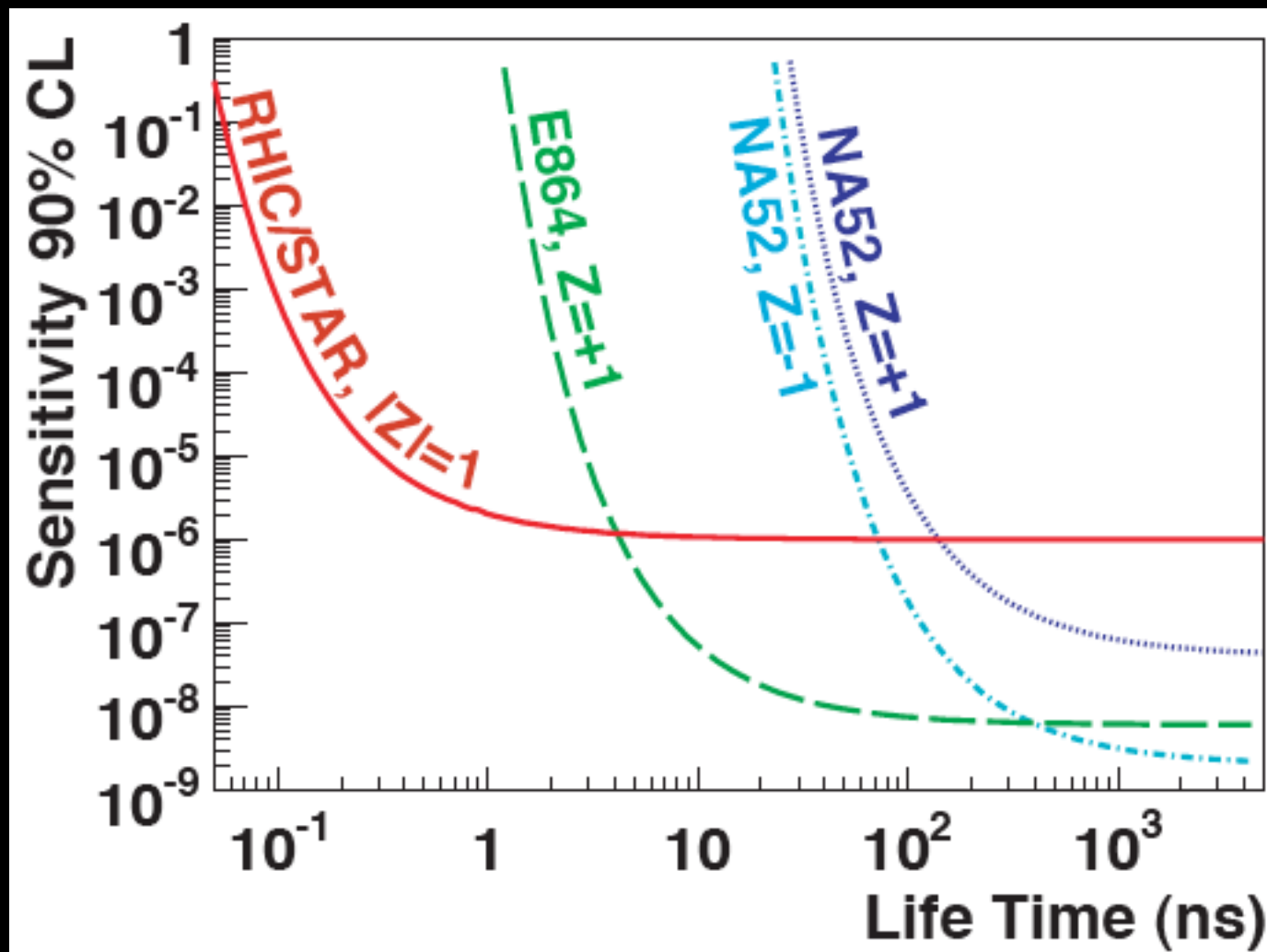
**Needs vertex detector at
fragmentation region.**

Summary

- **RHIC is an ideal machine for exotic/antimatter production.**
- **STAR is in excellent position for exotic/antimatter/rare-decay search.**
- **STAR has made important discoveries. With more proposed upgrades (HLT, DAQ10k, phase II pp2pp etc.), STAR will significantly broaden its search range for new/exotic phenomena.**
- **Together, we can expand RHIC's research horizon.**

Backup Slides

Upper Limit of Strangelet Production in Forward Region



STAR, PRC 76, 011901 (2007)